United States Patent [19] [11] 4,223,734
Lekas [45] Sep. 23, 1980

[54] PROCESS OF BREAKING AND RENDERING PERMEABLE A SUBTERRANEAN ROCK MASS

[75] Inventor: Mitchell A. Lekas, Concord, Calif.
[73] Assignee: Geokinetics Inc., Concord, Calif.

[21] Appl. No.: 959,070
[22] Filed: Nov. 9, 1978
[51] Int. Cl.[2] E21B 43/263; E21C 43/00; E21B 43/28
[52] U.S. Cl. 166/299; 166/308; 102/23; 299/4; 299/13
[58] Field of Search 166/299, 308, 309, 295, 166/259, 271; 299/4, 13; 102/23

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Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—Warren, Chickering & Grunewald

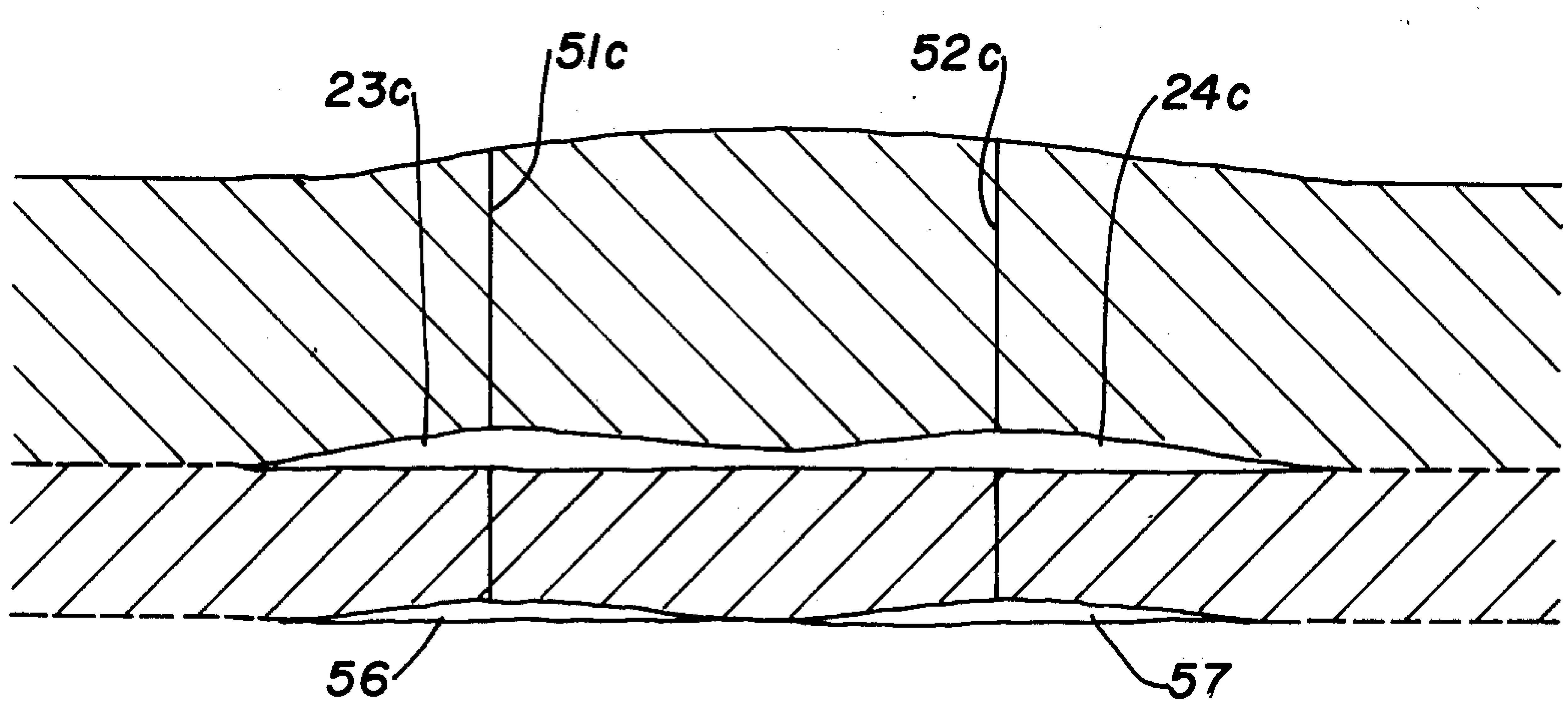
[57] ABSTRACT

The process of the present invention involves the following steps:

- producing, as by hydrofracing, a substantially horizontal fracture in the subterranean rock mass to be processed;
- emplacing an explosive charge in the mass in spaced juxtaposed position to the fracture;
- enlarging the fracture to create a void space thereat, an initial lifting of the overburden, and to provide a free face juxtaposed to and arranged to cooperate with the emplaced explosive charge; and
- exploding the charge against the free face for fragmenting the rock and to distribute the space, thus providing fractured, pervious, rubble-ized rock in an enclosed subterranean chamber.

Firing of the charge provides a further lifting of the overburden, an enlargement of the chamber and a larger void space to distribute throughout the rubble-ized rock within the chamber. In some forms of the invention an explosive charge is used to produce a transitory enlargement of the fracture, and the juxtaposed emplaced charge is fired during the critical period of enlargement of the fracture.

10 Claims, 18 Drawing Figures



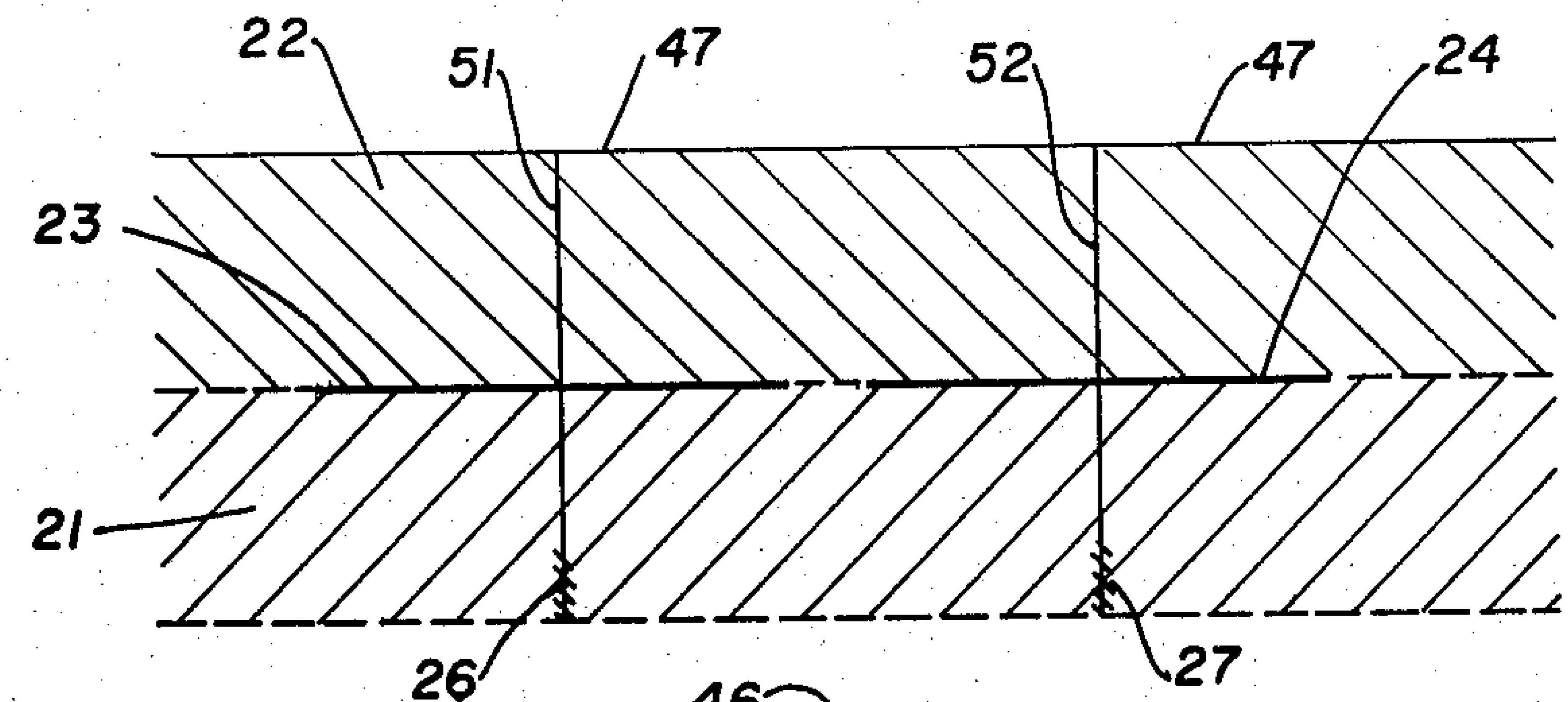


Fig. 1

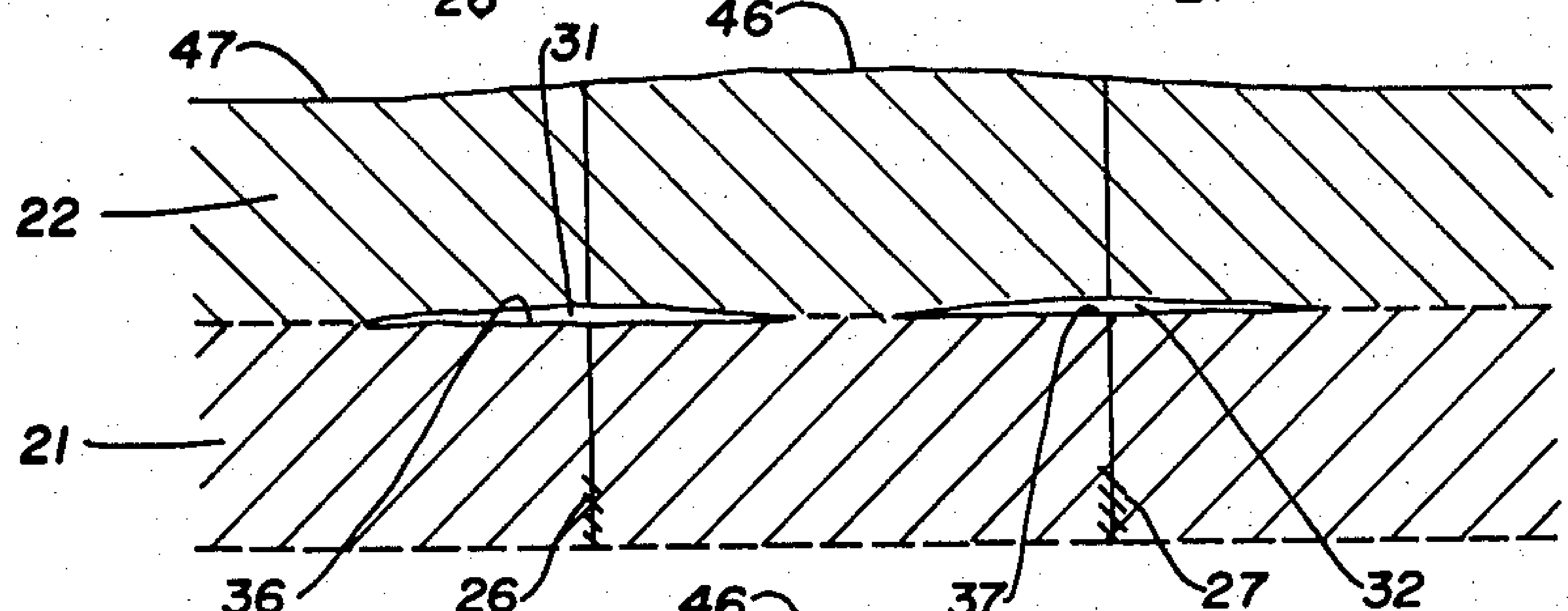


Fig. 2

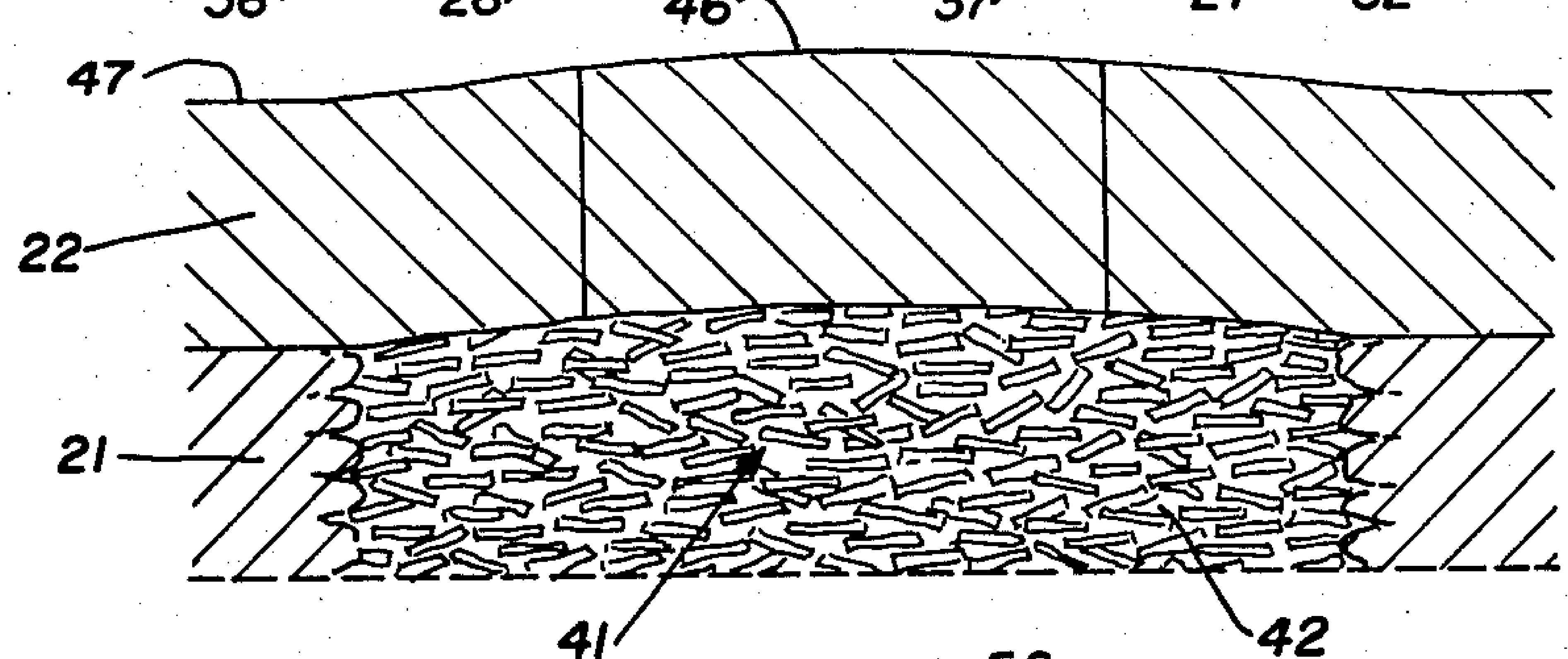


Fig. 3

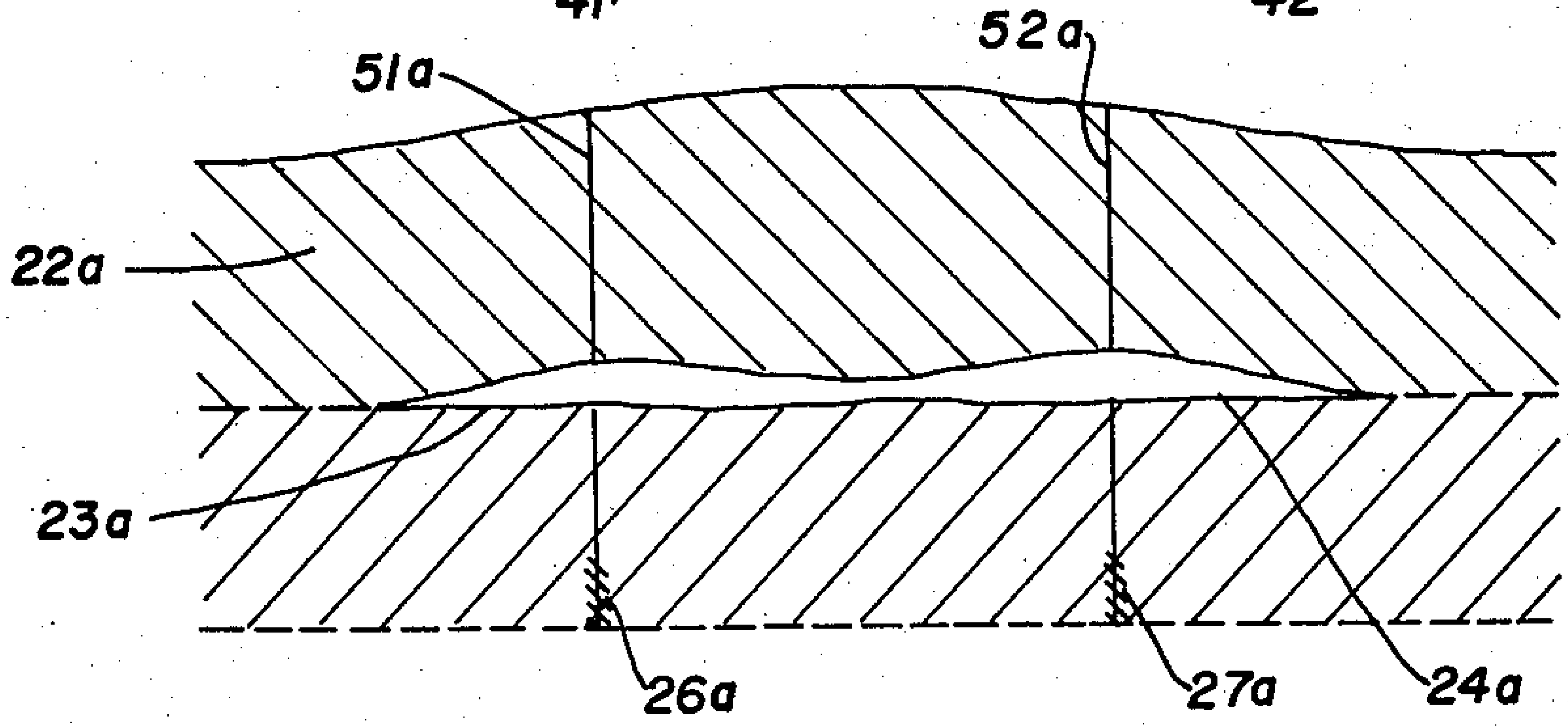


Fig. 4

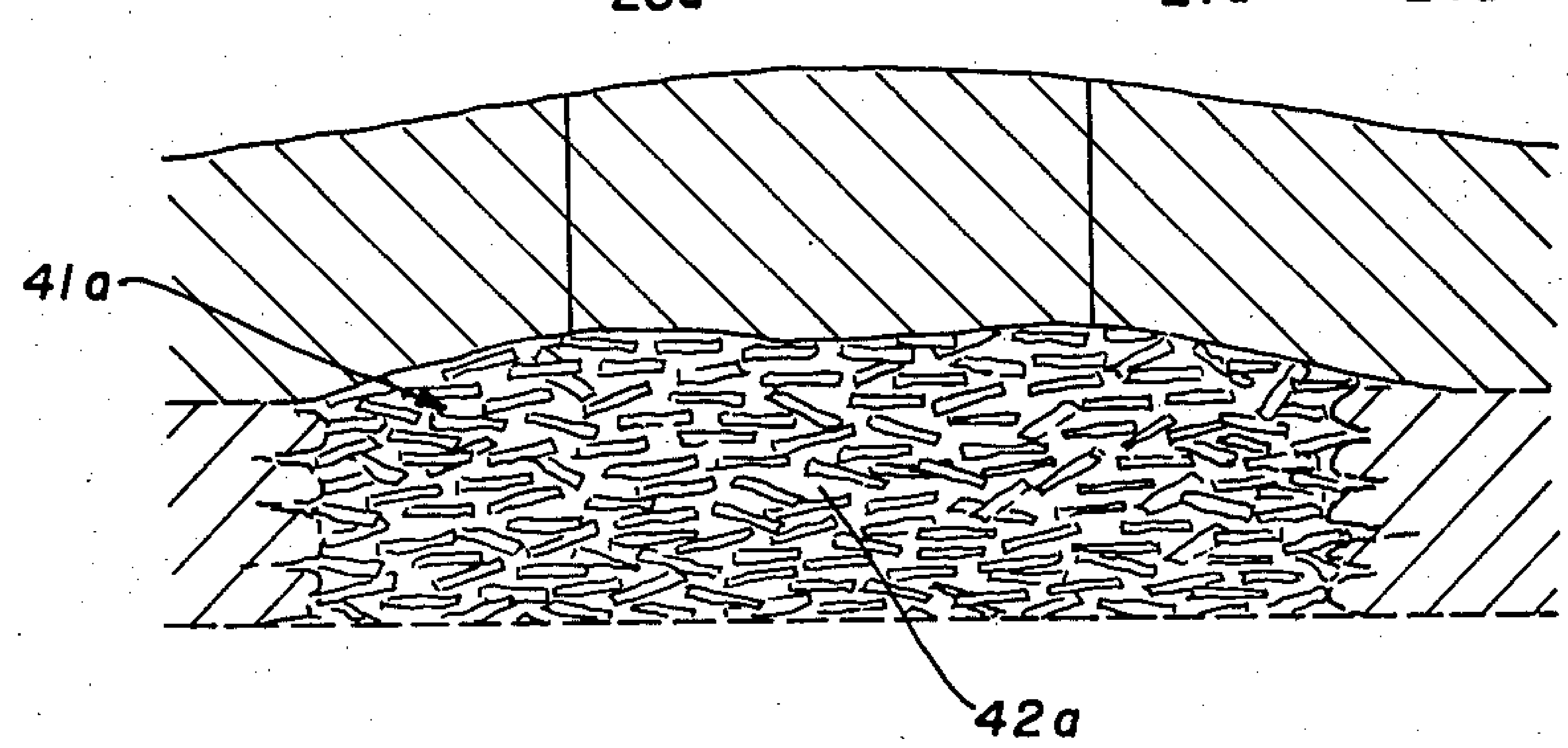


Fig. 5

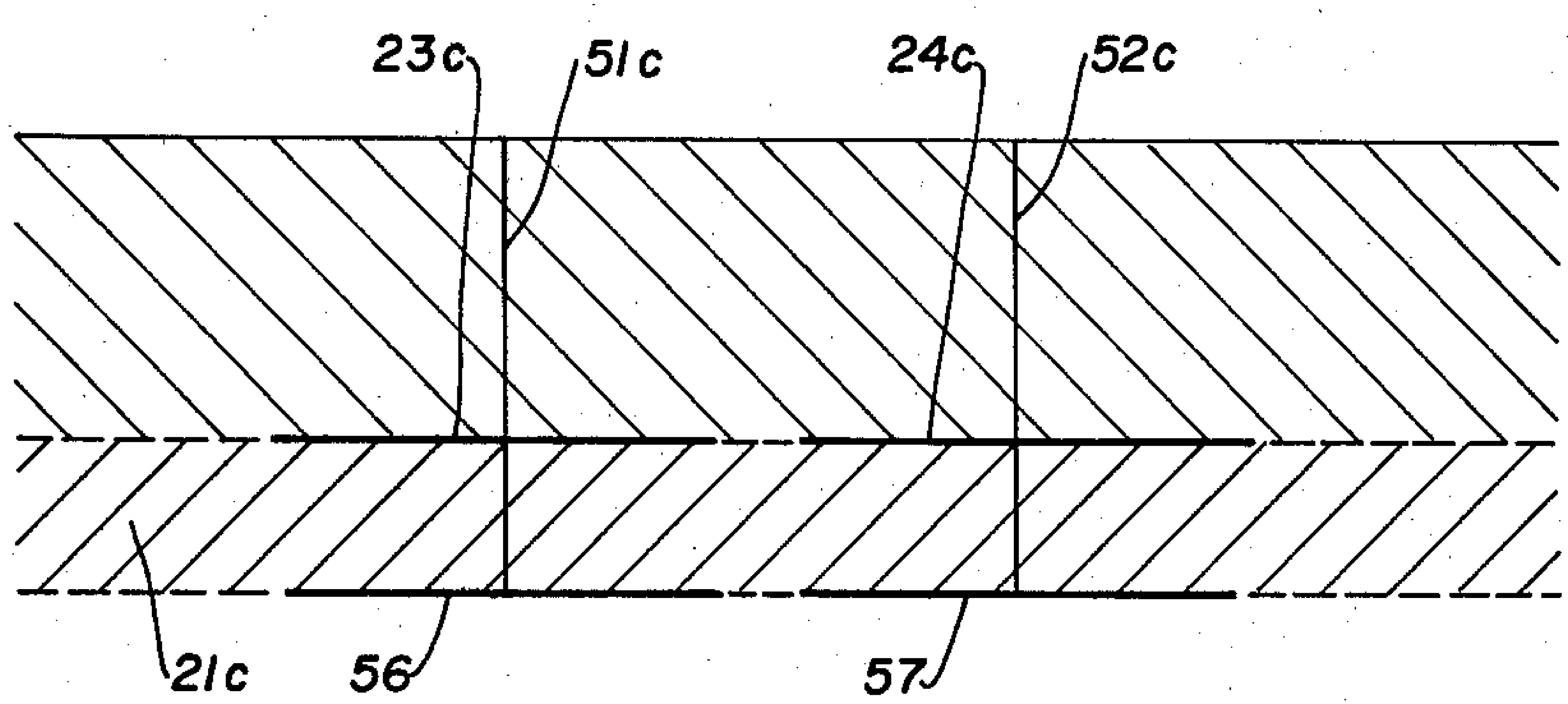


Fig. 6

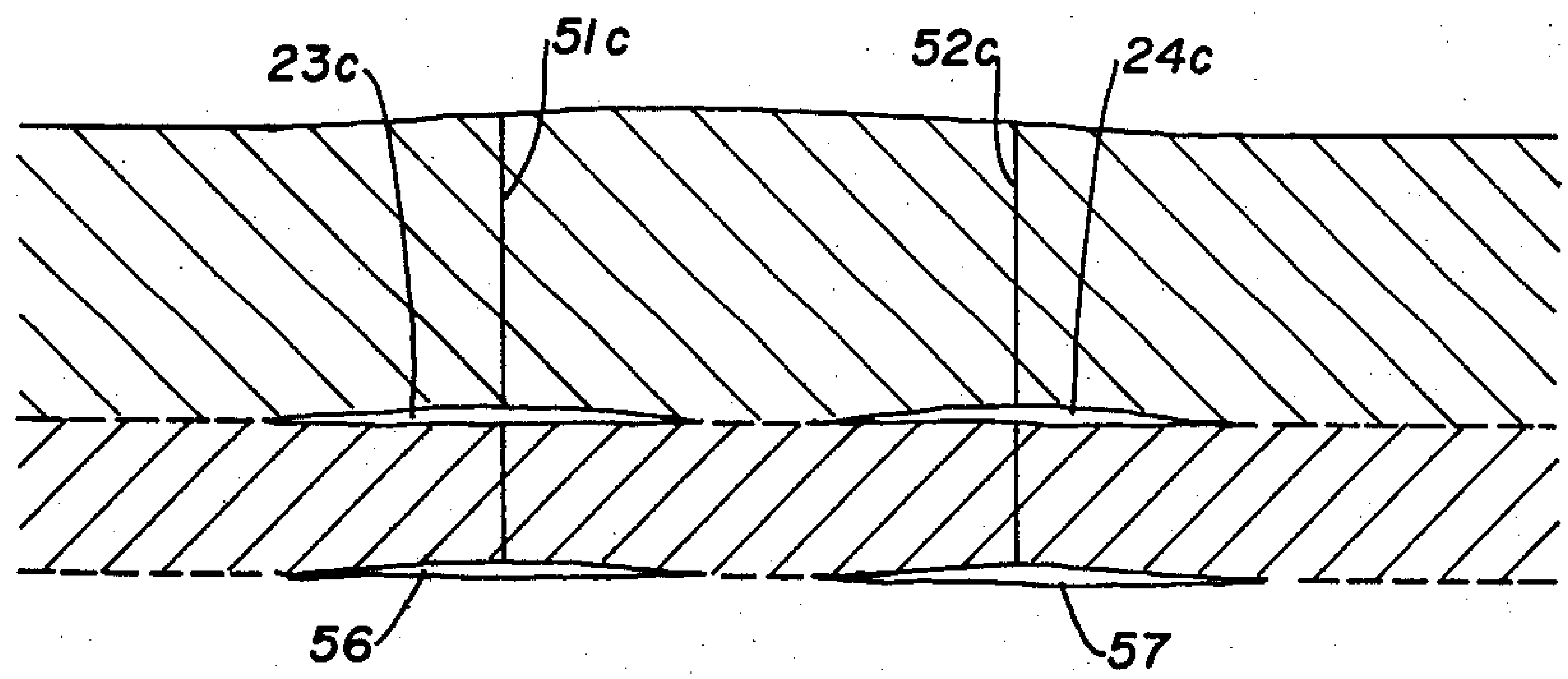


Fig. 7

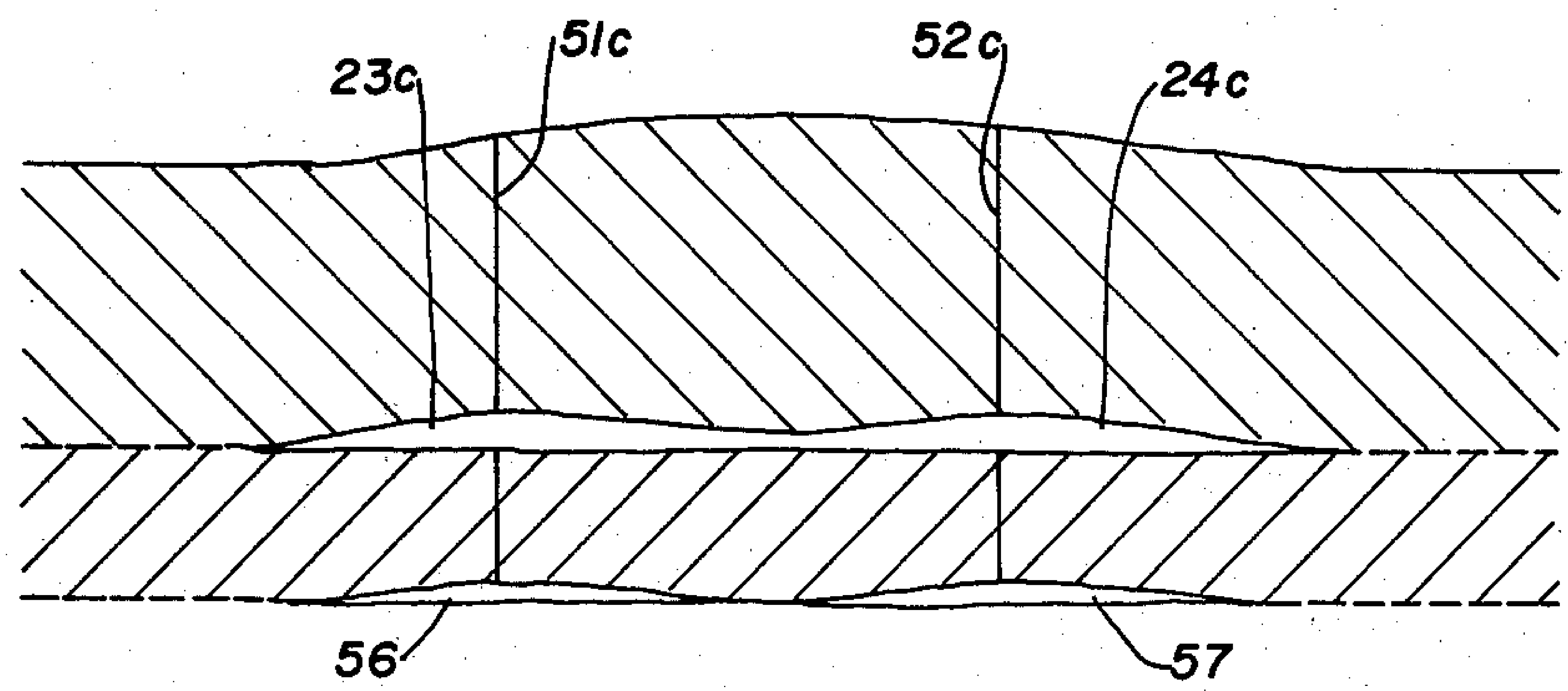


Fig. 8

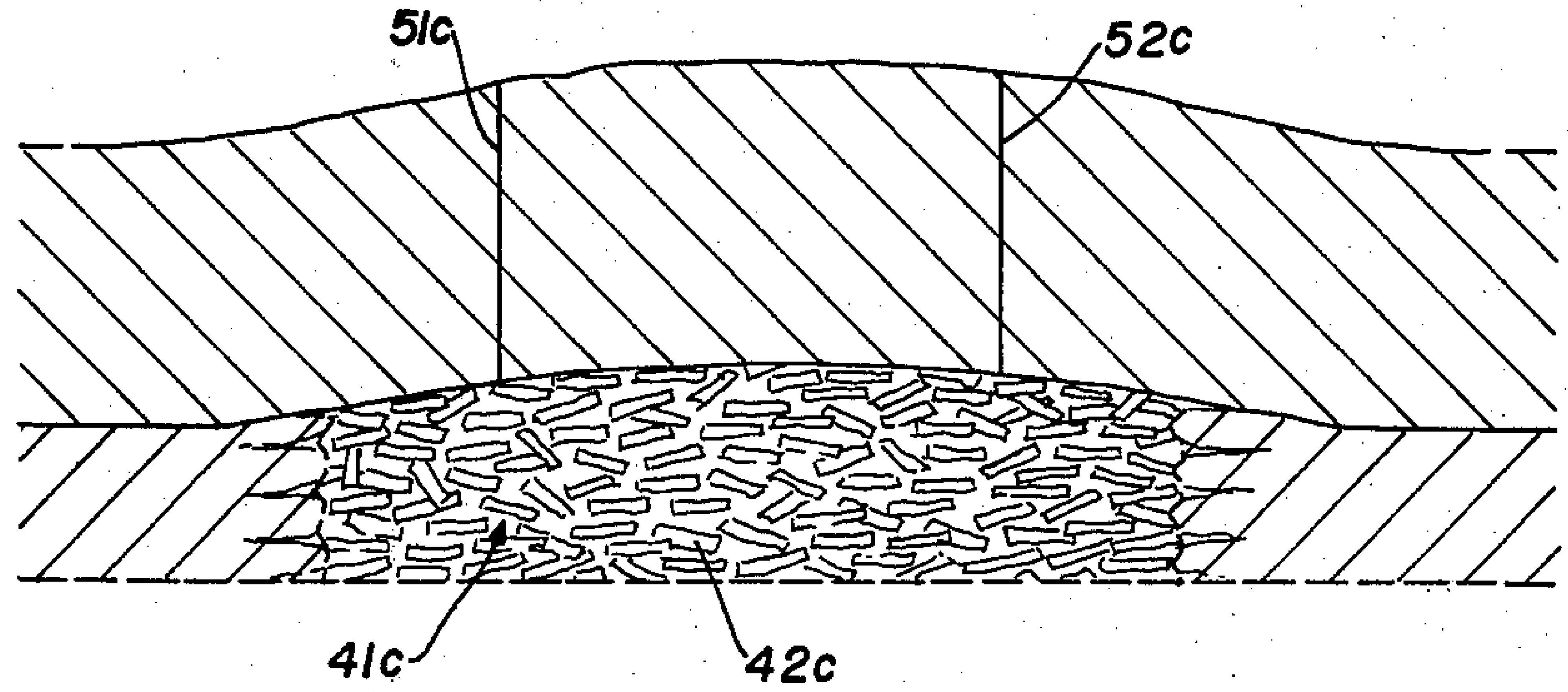


Fig. 9

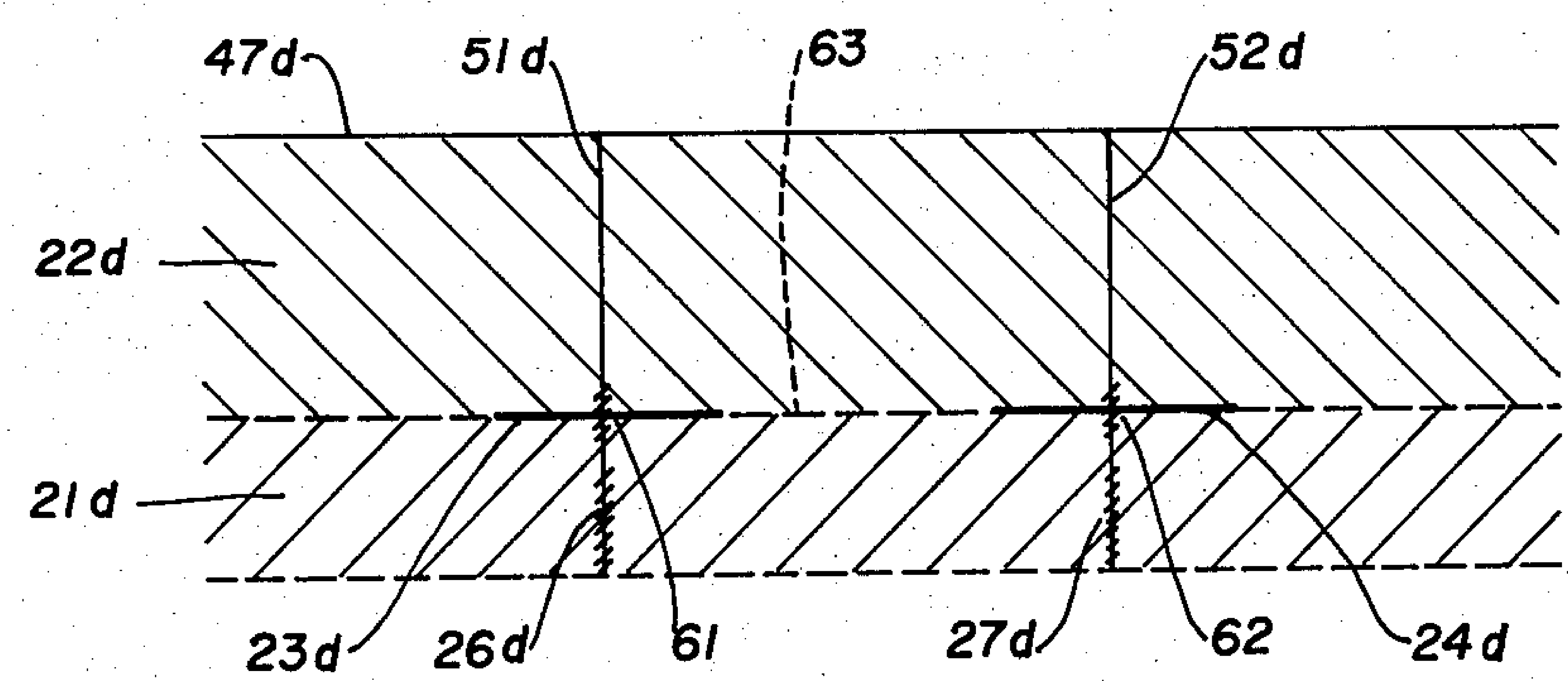


Fig. 10

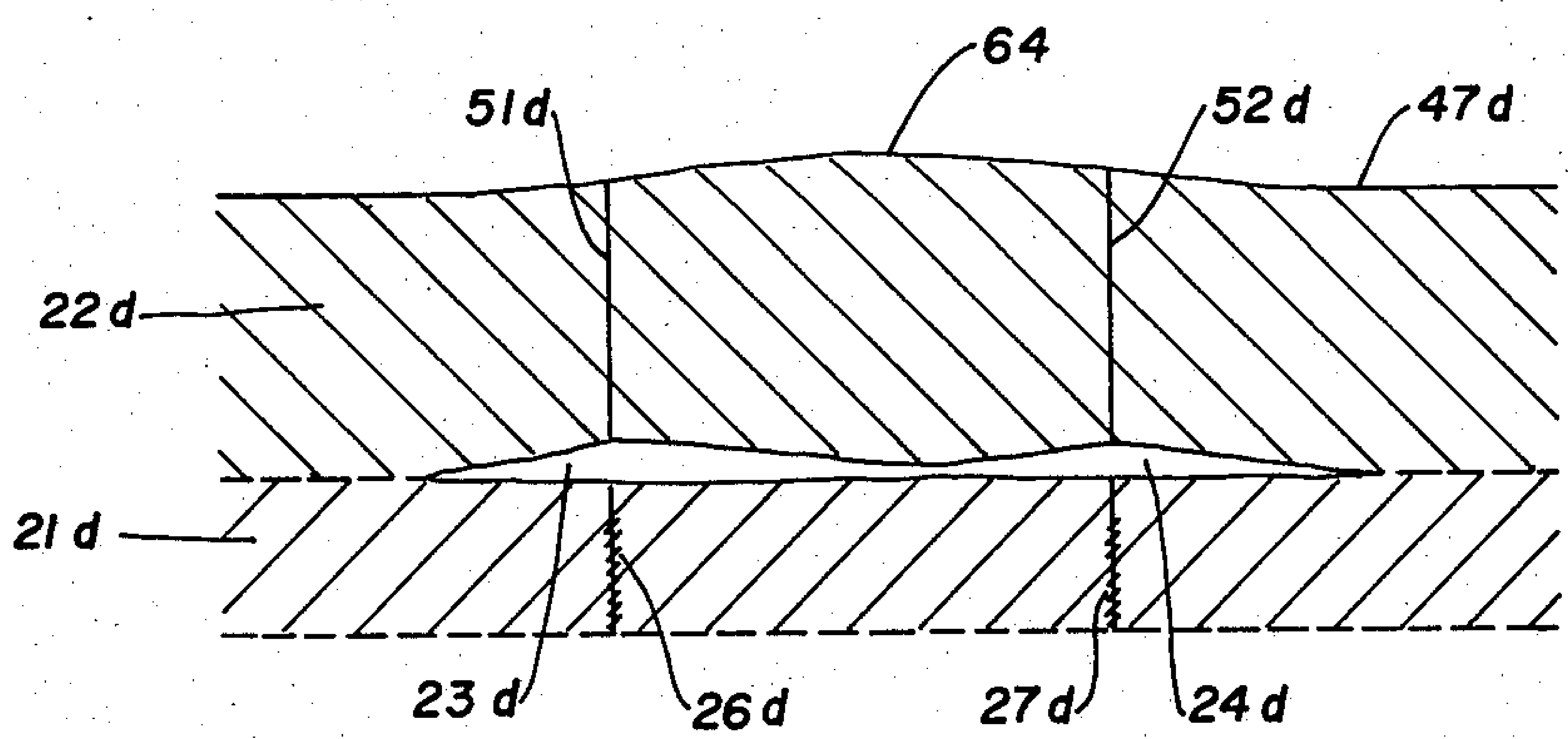


Fig. 11

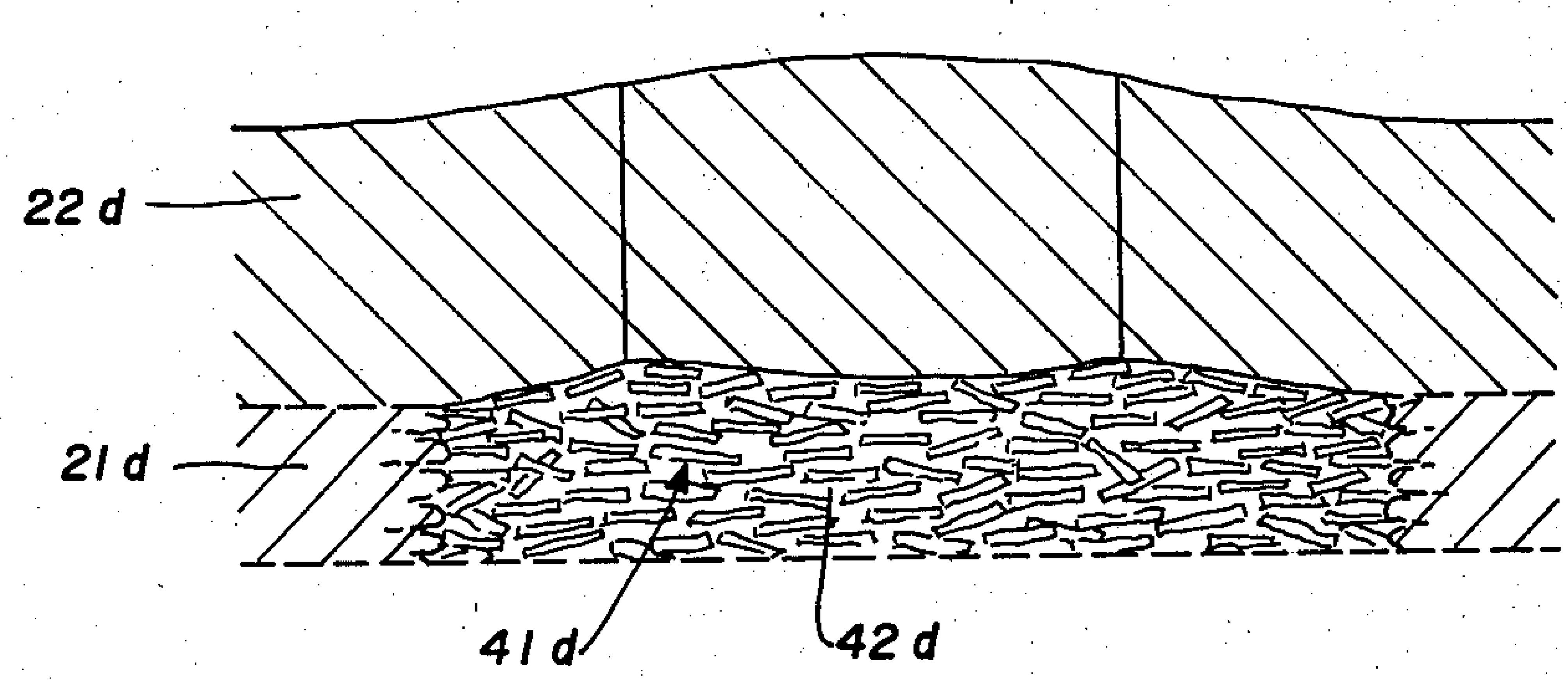


Fig. 12

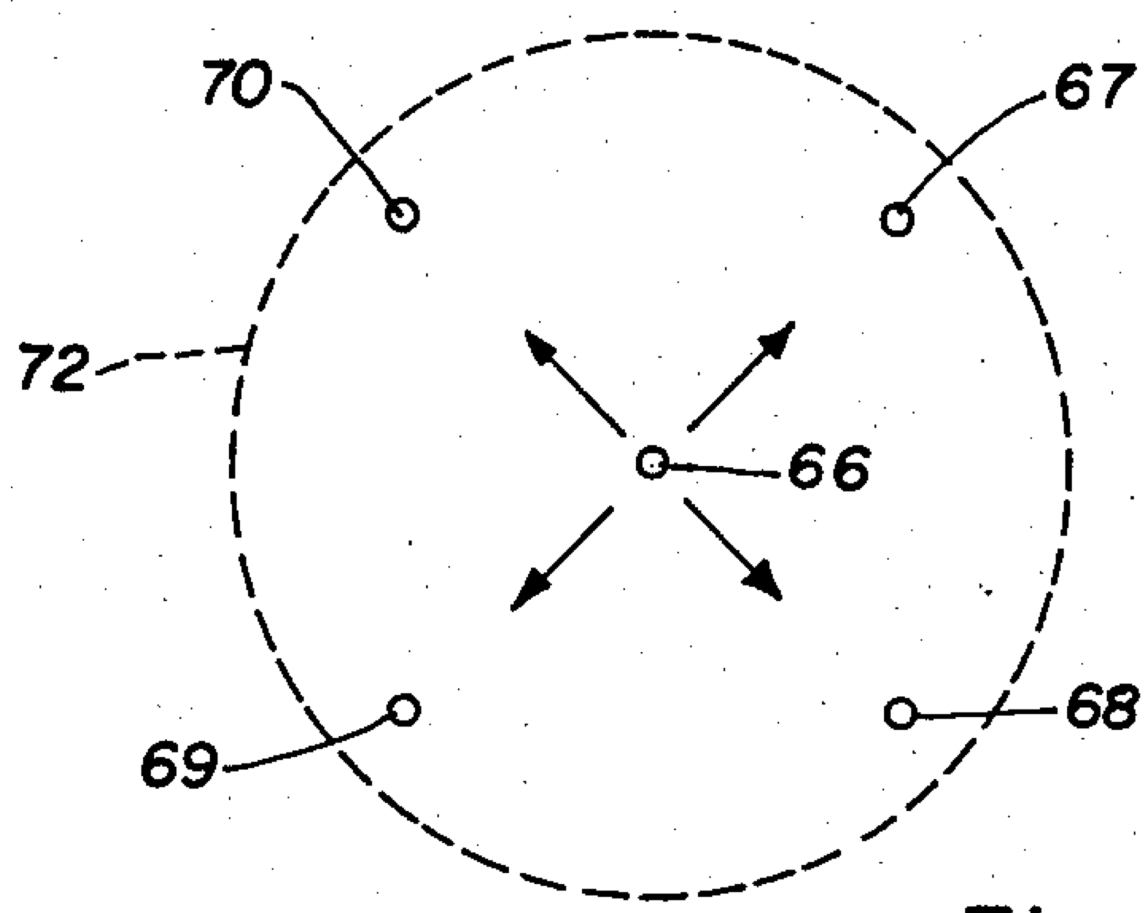


Fig. 13

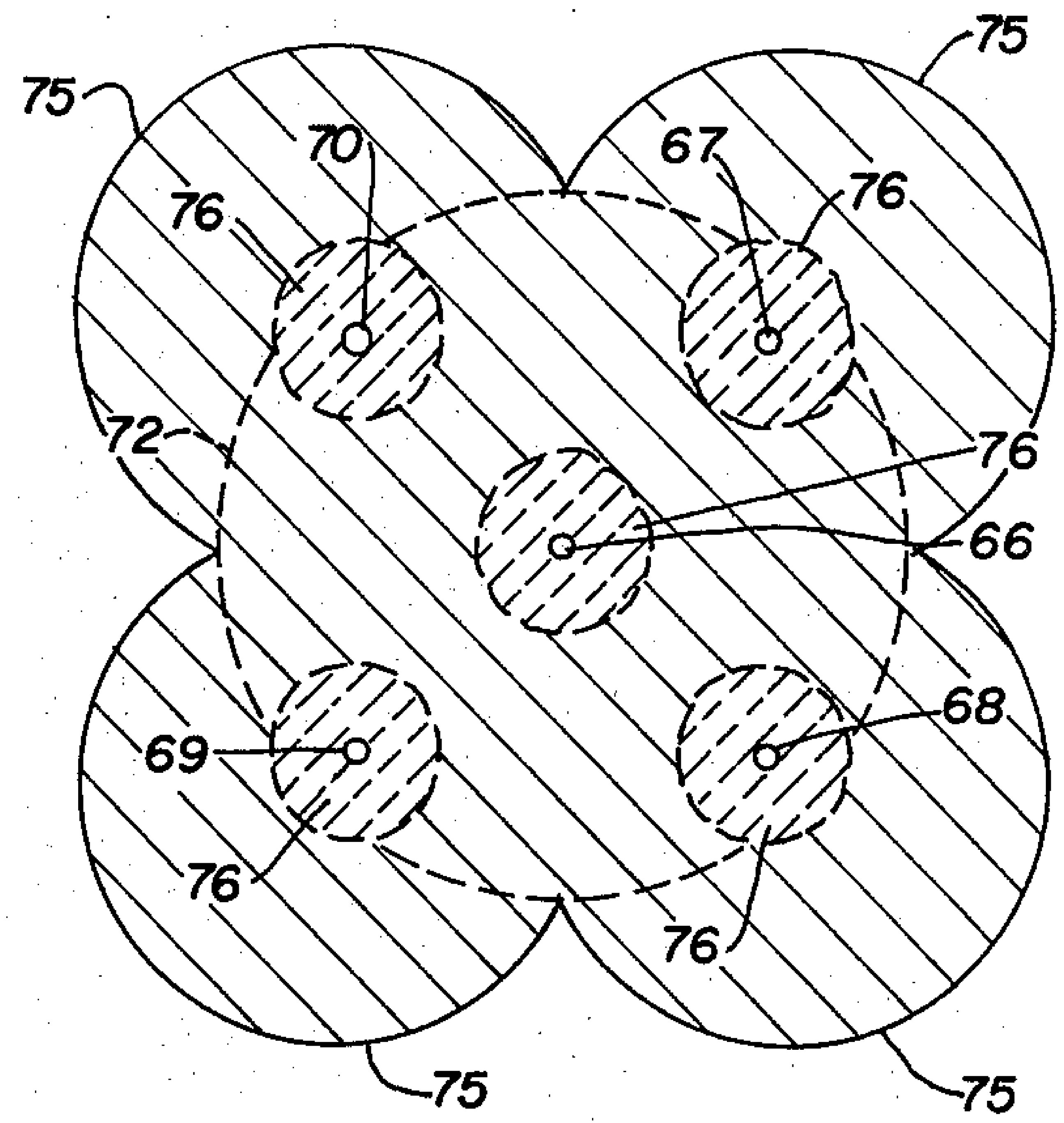


Fig. 14

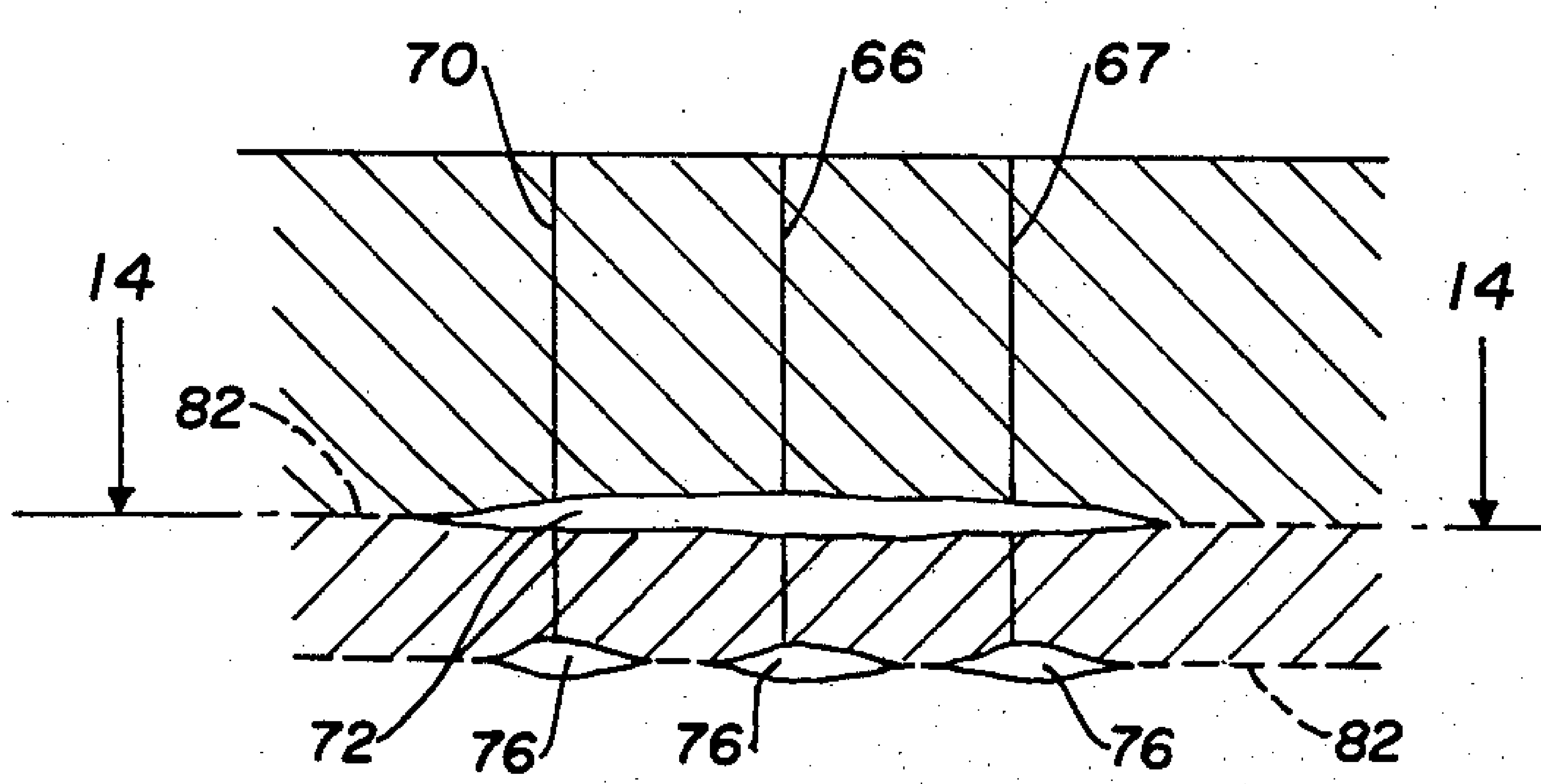


Fig. 15

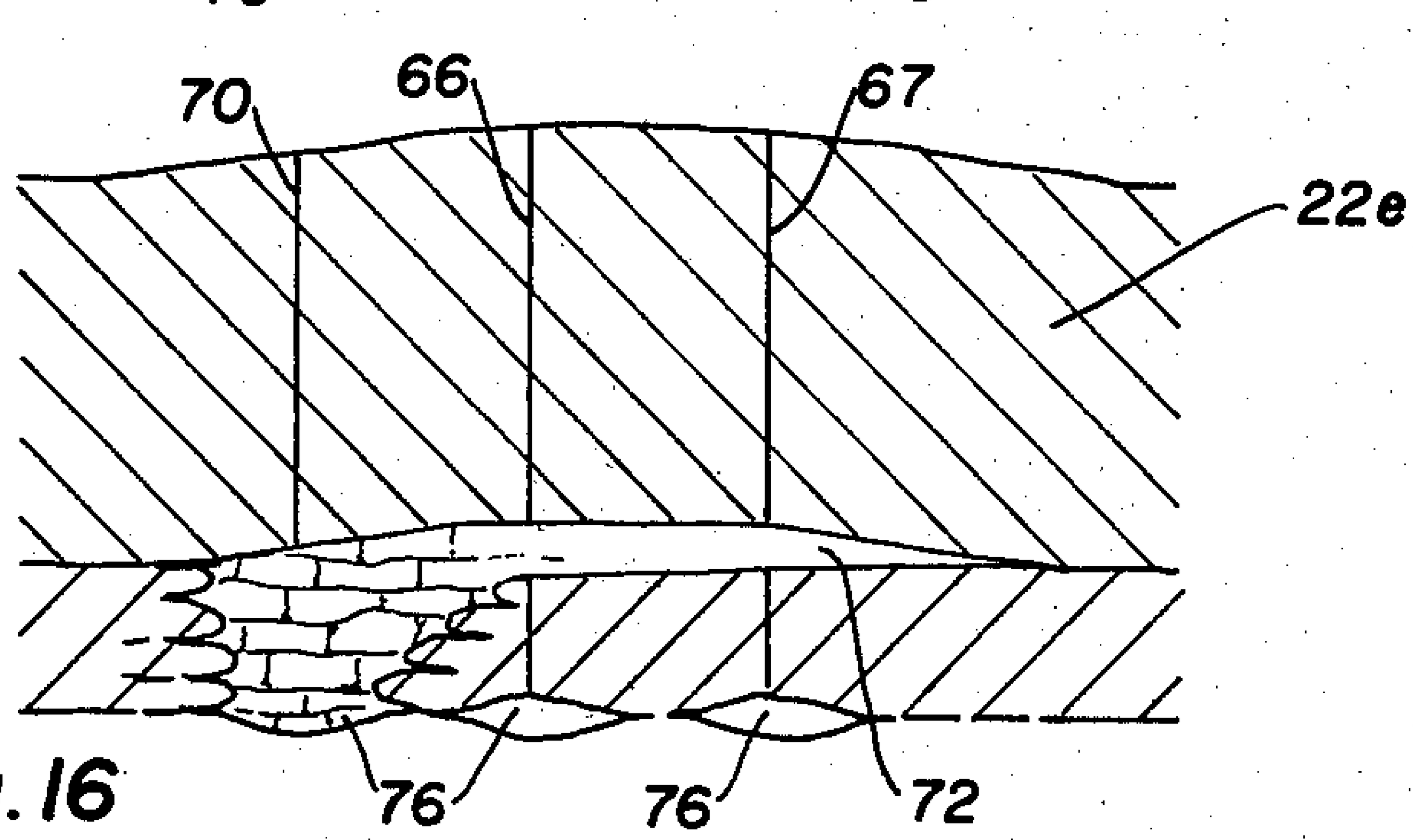


Fig. 16

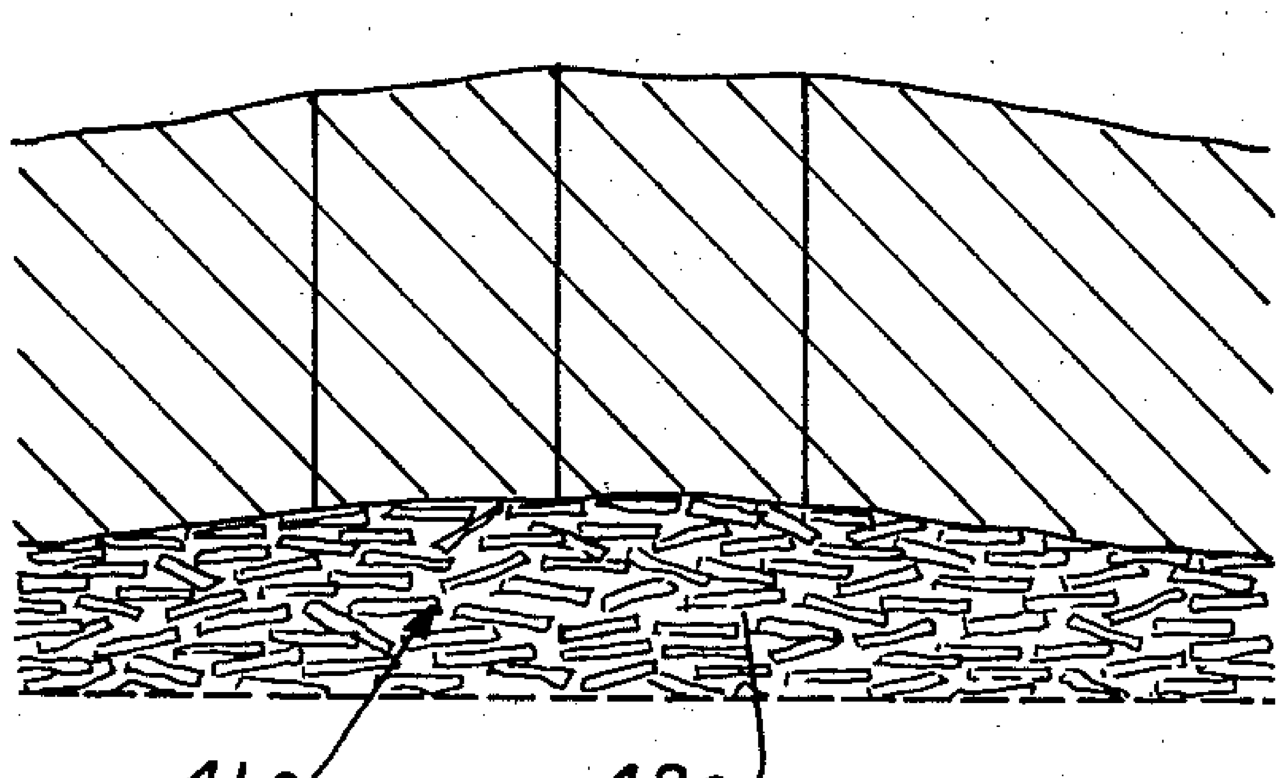


Fig. 17

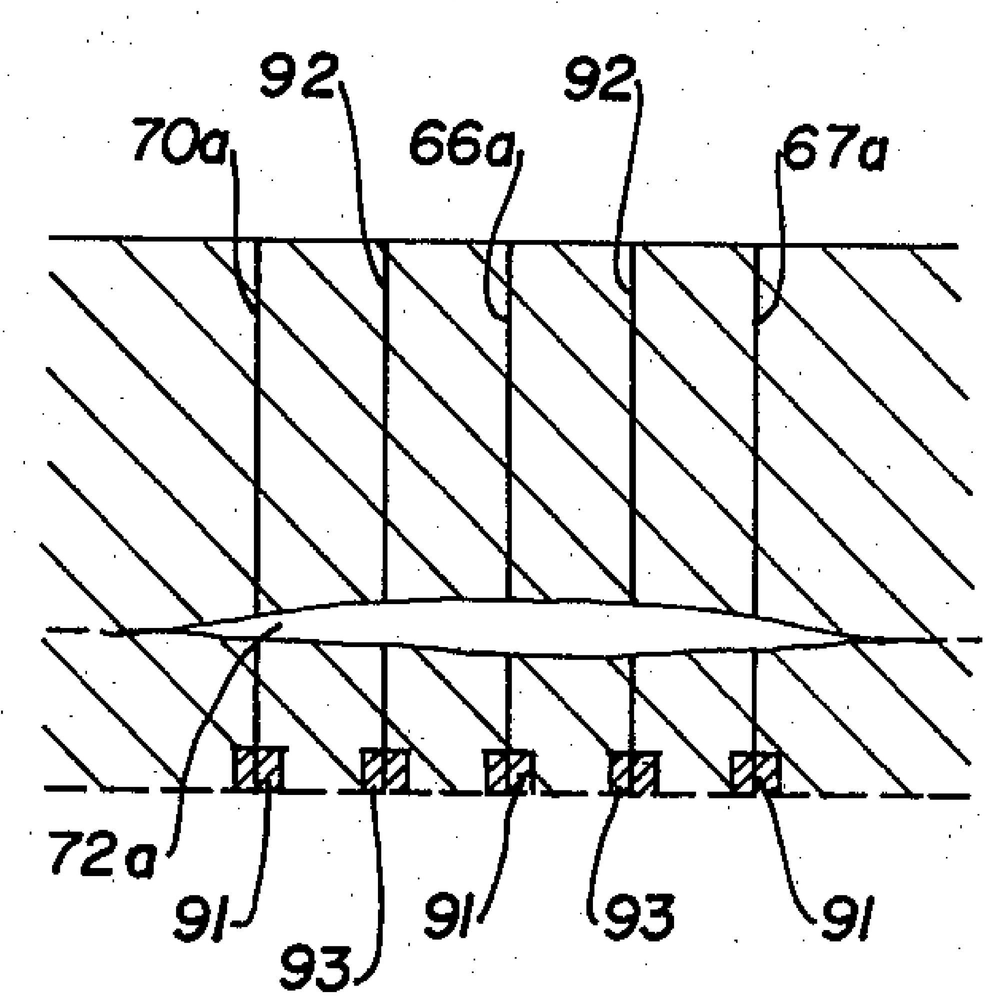


Fig. 18

PROCESS OF BREAKING AND RENDERING PERMEABLE A SUBTERRANEAN ROCK MASS

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates to processes for producing an underground zero of fragmented and pervious material which may be used as a storage area, as a passage or aquifier, for treatment of materials, for ore body leaching or recovering of carbonaceous materials from subterranean deposits, etc. The present process is considered to be a general one of breaking and rendering permeable a mass of rock underneath an impermeable mass of rock and may be used in the production of in situ retorts in oil shale deposits, extracting oil from tar sands, in situ gasification of coal, leacing copper out of a copper deposit or uranium out of a uranium deposit. Essentially, the present process is directed to the selective breaking of a mass of rock in the ground without breaking all of the rock up to the surface.

2. Description of Prior Art

As is well known, large amounts of hydrocarbon oil are contained in subterranean oil shale deposits, and the economic recovery of such oil, and/or hydrocarbon gases, has been a long-sought-after objective. Access to the oil shale may be obtained by removing the overburden by strip mining procedure, However, such procedure is both costly and deleterious to the terrain. Efforts have accordingly been made to extract the oil and valuable hydrocarbon gases by the production of subterranean retorts in the oil shale deposit with minimum disturbance of the land surface. An example of such procedure is disclosed in my U.S. Pat. No. 4,037,657. Another technique for the production of the subterranean retort is the application Ser. No. 895,243 of Daniel P. Zerga, filed Apr. 10, 1978.

SUMMARY OF THE INVENTION

I have found that the breaking and the rendering permeable of a subterranean rock mass may be effectively and efficiently accomplished by the process of the present invention which consists briefly of:

- producing, as by hydrofracing, a fracture in the rock mass;
- emplacing an explosive charge in the rock in spaced confronting relation to the fracture;
- enlarging the fracture to create thereat space and a free face at a side of the fracture confronting the charge; and
- exploding the charge against the free face for fragmenting the rock and to distribute the space, thus producing a chamber filled with fractured, pervious, rubble-ized rock.

An object of the present invention is to provide a process of the character described which is sure, efficient, and effective in the production of the subterranean chamber of fractured, pervious, rubble-ized rock with minimum disturbance of, or damage to, the ground surface; and while preserving, intact and with good integrity, an overburden lid or closure for the chamber.

Another object of the present invention is to provide a process of the character described, requiring minimum ground preparation, and which uses dependable techniques and efficient use of explosives as well as avoiding wasteful escape to the atmosphere of explosively generated gases.

The invention possesses other objects and features of advantage, some of which of the foregoing will be set forth in the following description of the preferred form of the invention which is illustrated in the drawings accompanying and forming part of this specification. It is to be understood, however, that variations in the showing made by the said drawings and description may be adopted within the scope of the invention as set forth in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical cross-sectional view of a ground preparation used in practicing the invention.

FIG. **2** is a view similar to FIG. **1**, but showing an intermediate step of the process.

FIG. **3** is a cross-sectional view similar to FIGS. **1** and **2**, but showing the completed subterranean chamber filled with fractured, pervious, rubble-ized rock.

FIG. **4** is a vertical cross-sectional view of an interim step in a second form of the invention, and

FIG. **5** is a similar view of the completed process.

FIG. **6** is a vertical cross-sectional view depicting a third form of the invention; and

FIGS. **7**, **8**, and **9** depict interim and completed stages of the process.

FIG. **10** is a vertical cross-sectional view depicting a fourth form of the process of the present invention.

FIGS. **11** and **12** depict interim and completed stages of such process.

FIG. **13** is a plan view depicting a fifth form of the invention.

FIG. **14** is a cross-sectional view of the ground preparation of FIG. **13**, and is taken substantially on the line of **14—14** of FIG. **15**.

FIG. **15** is a vertical sectional view of the ground preparation depicted in FIGS. **13** and **14**, for breaking and rendering permeable a rock mass.

FIGS. **16** and **17** are vertical sectional views depicting interim and completed stages of the process illustrated in FIGS. **14** and **15**.

FIG. **18** is a vertical cross-sectional view depicting a further alternative form of the process of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The process of the present invention is designed for breaking and rendering permeable a subterranean mass of rock **21** covered by an overburden **22** and comprises, briefly, the producing in the rock of one or more fractures **23** and **24**; emplacing an explosive charge **26** in the rock mass in spaced confronting relation to the fracture; enlarging the fracture, see FIG. **2**, to create thereat space **31** and a free face **36** at a side of the fracture confronting charge **26**; and exploding charge **26** against free face **36** for fragmenting rock therebetween and to distribute space **31**, thus producing a chamber **41** filled with fractured, pervious, rubble-ized rock **42**. In the foregoing process, overburden **22** may be raised slightly with the enlarging of fracture **23**, producing a small crown **46** at ground surface **47**. On firing of charge **26**, the explosive gases released and contained in chamber **41** produce a further lifting of the overburden, see FIG. **3**, thus affording additional space within the chamber for distribution through the rubble-ized rock to provide requisite permeability. The enlargement of fracture **23** provides a medium therein of different density than the surrounding rock to create a reflecting surface for explosive **26**.

The hydrofrac process for producing a fracture in subterranean rock is well understood in the art. A fluid pressure medium, such as water, is forced under pressure into the rock at the location where fracturing is to be initiated. As the fracturing fluid is forced into the rock, the fracture is caused to propagate away from the point of entry of the fluid. In the present case, a bore hole **51** is drilled from the surface **47** vertically down into the rock **21**, a fluid inlet pipe (not shown) is sealed in bore hole **51** and has its lower discharge end located at the plane where hydrofracing is to occur, bore hole **51** being stemmed below the plane of intended fracture. The fracture produced is a thin crack which may be propagated out in all directions and for many feet from the point of origin. Thickening agents in the hydrofrac fluid may be employed to increase, somewhat, the depth of the fracture, and to carry sand grains out into the fracture.

There are several methods which may be used for making the requisite enlargement in the fracture to carry out the purposes of the present invention. One method is the use of one of a number of foams that may be injected into the fracture, the foam being quite viscous in flowing through the fracture, and accordingly developing lifting force on the overburden to develop the space and free face above discussed. Since the foam is mostly air, it has excellent reflecting characteristics. The foam may be a normal, unstable foam that would break down in time, e.g., a liquid-air-type foam, or it could be some kind of a setting material, e.g., Styrofoam (polystyrene), which would stand for a longer period of time. Also, the liquid-foam-producing components may be selected to provide, within themselves, a strong expanding force. The required force need overcome the weight of the overburden, and the foaming characteristics may be tailored to exert maximum lifting force. The overburden pressures involved in this application are essentially the lithostatic pressure of the overlying rock, which is about one pound per square inch per foot of distance from the fracture to the surface. It is contemplated that the present invention will commonly be used at working depths in the order of 200 to 600 feet, which would involve about 200 psi to 600 psi of overburden pressure. Aside from the expanding power of the foam itself, pressures of this magnitude may readily be generated by a pump forcing the hydrofrac liquid into the crack.

With reference to FIGS. **1–3**, a plurality of bore holes, such as **51** and **52**, may be used to produce a pair of hydrofracs **23** and **24**, preferably on or near a common plane. Charge **26** may be emplaced in the lower end of bore hole **51** and a similar charge **27** may be emplaced in the lower end of bore hole **52**, thus positioning these charges in proper spaced confronting relation to fractures **23** and **24**. The latter may then be first opened using one of the foam techniques discussed above, thus optimizing the reflective characteristics of the fractures and creating spaces **31** and **32**, and free faces **36** and **37**, (see FIG. **2**). Subsequent firing of charges **26** and **27** provide the generally increased volume of rubble-ized rock **42**, as seen in FIG. **3**. Further enlargement of the enclosed retort chamber **41** and rubble-ized rock mass **42** may be effected by the use of additional numbers of bore holes.

Another technique of the present invention, and illustrated in FIGS. **4** and **5** of the drawings, is the use of an explosive for producing a transitory enlargement of the hydrofrac. In such case, and as an important feature of the present invention, the fragmenting charges confronting the transistorily enlarged hydrofrac are fired during the period of enlargement. With reference to FIG. **4**, fractures **23***a* and **24***a* may be first formed by hydrofracing, as illustrated in FIG. **1**, liquid explosive may then be pumped into the fractures and fired to produce a transitory opening of the fractures as seen in FIG. **4**. Thereafter, charges **26***a* and **27***a* emplaced in the lower ends of bore holes **51***a* and **51***b* are fired to produce rubble-ized rock **42***a* in chamber **41***a*. The firing of liquid explosive in fractures **23***a* and **24***a* provides an initial uplift of overburden **22***a*, as seen in FIG. **4**, and the explosive power of charges **26***a* and **27***a* produces still a further lifting of the overburden as seen in FIG. **5**. The detonation of the liquid explosive fills the fracture with gases formed by the explosion to provide the desired reflecting surface for the lower emplaced explosive charges **26***a* and **27***a*. A delay is used in firing these latter charges to coincide with the expansion of the fractures to optimum size.

A further form of the invention is illustrated in FIGS. **6–9**, wherein the fragmenting charges are emplaced in other fractures as liquid explosives. With reference to FIG. **6**, there is first prepared, in the rock **21***c*, substantially vertically superimposed, substantially horizontally extending fractures **23***c* and **56**, which delineate between them the mass of rock to be fragmented. Liquid explosive is pumped into fractures **23***c* and **56** as seen in FIG. **7**. One of the liquid explosives, preferably the upper one, is fired to produce a transitory enlargement of the fracture as seen in FIG. **8**. Thereafter, the other liquid explosive is fired to produce a fragmenting of the rock between the fractures as seen in FIG. **9**. Fractures **23***c* and **56** may be produced by hydrofracing technique from bore hole **51***c*; and a second pair of laterally-spaced fractures **24***c* and **57** may be prepared using laterally-spaced bore hole **52***c*. These fractures may be charged in the manner discussed above, and fired simultaneously or with appropriate delays with their companion laterally spaced charges to produce rubble-ized rock **41***c* in a generally enlarged rubble-filled chamber **42***c*, as depicted in FIG. **5**. The use of two sets of such fractures is illustrated only. These may be replicated to scale up the area of fragmentation.

Another form of the present invention is illustrated in FIGS. **10–12**, wherein a plurality of bore holes **51***d* and **52***d* are drilled from the surface **47***d* vertically down through overburden **22***d* and into the area of rock **21***d* to be fragmented. Fractures **23***d* and **24***d* are formed in the upper regions of area **21***d* by conventional hydrofracing techniques. Thereafter, explosive charges **26***d* and **27***d* are emplaced in the lower ends of bore holes **51***d* and **52***d* and explosive charges **61** and **62** are emplaced in bores **51***d* and **52***d* at fractures **23***d* and **24***d*. Exploding of charges **61** and **62** will produce the injection of gases of explosion into fractures **23***d* and **24***d* resulting in a raising of overburden **22***d*, as seen by the crowning effect at **64** of the ground surface **47***d* in FIG. **11**. Firing of charges **61** and **62** produce a transitory opening of fractures **23***d* and **24***d* and a free face against which subsequent blasting of charges **26***d* and **27***d* may take place. Firing of charges **26***d* and **24***d* in timed relation to the opening of fractures **23***d* and **27***d* will produce a permeable rubble-ized rock volume **42***d* in subterranean chamber **41***d*.

A further modified form of the invention is illustrated in FIGS. **13** to **17** in which a number of bore holes **66**, **67**, **68**, **69**, and **70** are drilled in a pattern, such as a 5-spot pattern as seen in FIG. **13**. An initial fracture **72** is driven outwardly from bore hole **66**, and preferably propagated well past the peripheral pattern of bore holes **67–70**. Fracture **72** may be further enlarged by pumping a hydrofracting fluid into fracture **72** from bore holes **67–70**, see enlargements **75** in FIG. **14**.

Where such an extended fracture is to be used for the purpose of breaking and rendering permeable a rock mass, a plurality of fractures **76** is formed by hydrofracting from each of the bore holes **66–70** at positions vertically positioned below the enlarged fracture **72**. Liquid explosive may then be injected into fracture **72** and each of the fractures **76**. Firing of the explosive in fracture **72** is first effected to create a transitory enlargement thereof and a free face related to fractures **76**. Thereafter and in timed relation to the optimum enlargement of fracture **72**, charges in fractures **76** are fired against the free face produced at fracture **72** for fragmenting rock therebetween and generating a volume of gas which will produce a further lifting of the overburden. Fractures **76** may be extended laterally to connect in one large fracture. Where individual fractures are used, as here shown, suitable delays in the firing of the charges in fractures **76** may be used, as illustrated in FIG. **16** to maximize rock breakage.

A further alternative structure is illustrated in FIG. **18** wherein a plurality of charges **91** is emplaced in bore holes **66*a*–70*a*** below the enlarged hydrofrac **72*a*** produced as described above. Again, liquid explosive injected into fracture **72*a*** is fired to produce a transitory enlargement of the fracture and charges **91** are fired in timed relation to such enlargement, as above described, to effect fragmentation of the rock mass. Additional bore holes **92** may be drilled from the surface, not necessarily for assisting in production of hydrofrac **72*a***, but for emplacement of additional charges **93** below the enlarged fracture **72*a***.

Liquid explosive need not fill the entire plane of the fracture in which it is injected, but may penetrate sufficiently to occupy 10 to 50 percent of the fracture area. This is generally true of all of the forms of the present invention using liquid explosive. Any suitable, stable, pumpable liquid explosive, well known in the blasting art and available commercially, may be used for carrying out the processes of the present invention.

What is claimed is:

1. The process for breaking and rendering permeable a subterranean mass of rock comprising:
- hydrofracing substantially vertically superimposed substantially horizontally extending fractures in said mass delineating rock to be fragmented;
- pumping of a liquid explosive into one of said fractures;
- firing an explosive in the other of said fractures to produce a transitory enlargement thereof and to provide a free face; and
- firing said liquid explosive during the period of said enlargement.

2. The process of claim **1**, and pumping a liquid explosive into said other fracture to provide said second-named explosive and to provide said transitory explosive enlargement of said other fracture.

3. The process for breaking and rendering permeable a subterranean mass of rock comprising:
- boring a hole from the surface into said mass;

- hydrofracing a fracture from said bore hole;
- emplacing a first explosive charge in said bore hole spaced from said fracture;
- emplacing a second explosive charge in said bore hole at said fracture;
- exploding said second charge to produce a transitory enlargement of said fracture and space therein and a free face; and
- exploding said first charge during the period of said enlargement for fragmenting said rock between said charges and to distribute said space, thus producing fractured pervious rubble-ized rock in said area.

4. The process for breaking and rendering permeable a subterranean mass of rock comprising:
- hydrofracing a fracture in said mass;
- emplacing an explosive charge in said mass in spaced confronting relation to said fracture;
- firing an explosive in said fracture to produce a transitory enlargement thereof and a free face confronting said charges; and
- exploding said charge during the period of said enlargement and against said free face for fragmenting said rock and to distribute said space, thus producing a chamber filled with fractured pervious rubble-ized rock.

5. The process of claim **4**, said step of enlarging said fracture comprising the pumping into said fracture under pressure of a liquid explosive and firing said explosive.

6. The process of creating a fracture in a subterranean rock mass comprising:
- boring a plurality of substantially vertical holes from the surface into said mass, said holes being arranged in a pattern having a center hole and a plurality of outer holes circumferentially positioned around said center hole;
- hydrofracing from said center hole to produce a fracture driven outwardly therefrom to intersect said outer holes;
- injecting hydrofracing fluid through said outer holes into said fracture, thereby extending said fracture laterally and producing an enlargement thereof;
- emplacing explosive charges in said holes in spaced confronting relation to said fracture;
- firing an explosive in said fracture to produce a transitory enlargement thereof and a free face confronting said charges; and
- exploding said charges during the period of said enlargement.

7. The process of claim **6** for breaking and rendering permeable said rock mass comprising:
- hydrofracing from said outer holes a plurality of second fractures vertically offset from said first-named fracture;
- injecting liquid explosive into said first-named fracture;
- injecting liquid explosive in said second fractures;
- firing the explosive in said first-named fracture to effect enlargement thereof and creating a free face related to said second fractures; and
- firing said explosive in said second fractures against said free face for fragmenting said rock therebetween.

8. The process of claim **7**, said bore holes being arranged in a 5-spot pattern.

9. The process of claim **6** for breaking and rendering permeable said rock mass comprising:

injecting liquid explosive into said fracture;

emplacing second explosive charges in said outer bores at positions below said first fracture;

firing the explosive in said first fracture to effect enlargement thereof and creating a free face related to said second charges; and

firing said second charges against said free face for fragmenting said rock therebetween.

10. The process of claim 6,

hydrofracing from said outer holes a plurality of second fractures vertically offset from said first-named fracture;

injecting liquid explosive into said second-named fractures;

firing an explosive in said first-named fracture to produce a transitory enlargement thereof and a free face confronting said second fractures; and

firing said liquid explosives during the period of said enlargement and against said free face for fragmenting said rock and to distribute said space, thus producing a chamber filled with fractured pervious rubble-ized rock.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,223,734

DATED : September 23, 1980

INVENTOR(S) : Mitchell A. Lekas

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 1, line 9, delete "zero" and insert ---zone---; and

Col. 1, line 18, delete "leacing" and insert ---leaching---.

Signed and Sealed this

Twenty-third Day of *December 1980*

[SEAL]

Attest:

SIDNEY A. DIAMOND

Attesting Officer

Commissioner of Patents and Trademarks